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To: Docket Office, California Energy Commission (CEC)

From: C.K. Woo, E3

Re: 2007 IEPR – Portfolio Analysis, Docket No. 06-IEP-1M

Question

Should the techniques of mean-variance portfolio optimization, as discussed in the Bates White presentation and draft consultant report, be incorporated into long term utility procurement planning in California? If yes, are there any changes needed in the proposed analytical method? If not, are there better methods for incorporating cost risk and covariance between technologies into long term generation planning?

Response

As indicated by our prior submissions,[1] we concur that the efficient frontier (EF) approach is useful for utility long-term procurement planning. However, the framework in the two staff reports[2] can be improved via a clear relationship between (a) a load-serving-entity's (LSE) procurement cost expectation and variance, and (b) the LSE's retail sale obligation, forward purchase of conventional supply, forward purchase of renewable supply, and spot market transactions. This relationship also illustrates the necessary data to be collected.

[1] http://www.energy.ca.gov/2007_energypolicy/documents/2007-06-04_workshop/public_comments/

[2] (1) PORTFOLIO ANALYSIS AND ITS POTENTIAL APPLICATION TO UTILITY LONG-TERM PLANNING, http://www.energy.ca.gov/2007publications/CEC-200-2007-012/CEC-200-2007-012-SD.PDF; (2) A MEAN-VARIANCE PORTFOLIO OPTIMIZATION OF CALIFORNIA'S GENERATION MIX TO 2020, http://www.energy.ca.gov/2007publications/CEC-300-2007-009/CEC-300-2007-009-D.PDF

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In what follows, we explain the relationship in a 1-period model of LSE procurement of three generic categories of electricity: spot energy, forward energy and renewable energy. Though tedious, extending the 1-period model to a multi-period one is mathematically straightforward. Similarly, one can delineate each electricity category into sub-categories (e.g., solar, wind, small hydro in the renewable energy category), or add another category (e.g., utility owned generation and tolling agreements), at the expense of computational complexities.

To develop the relationship, we define:

- Q = Sale obligation (MWH) which is randomly distributed with forecast mean μ_Q and variance σ_Q^2, possibly based on a sales forecast.
- P = Spot market price ($/MWH), which is randomly distributed with forecast mean μ_P and variance σ_P^2, possibly based on a price forecast.[3]
- X = Forward purchase (MWH) at fixed price F ($/MWH). The forward purchase quantity may be based on a *hypothetical* procurement plan that the LSE may choose, and the fixed price can be based on the forward market price data and the market price referent (MRP) research.
- Y = Random renewable output (MWH), with forecast mean μ_R and variance σ_R^2, which is bought at fixed price R ($/MWH). To capture a renewable portfolio standard (RPS) target of α%, we set $(\mu_R / \mu_Q) \geq \alpha$. Thus, the renewable energy

[3] Woo, C.K., I. Horowitz, N. Toyama, A. Olson, A. Lai, and R. Wan (2007) "Fundamental Drivers of Electricity Prices in the Pacific Northwest," Advances in Quantitative Analysis of Finance and Accounting, forthcoming; Woo, C.K., I. Horowitz and K. Hoang (2001) "Cross Hedging and Value at Risk: Wholesale Electricity Forward Contracts," Advances in Investment Analysis and Portfolio Management, 8, 283-301

forecast may be based on a *hypothetical* renewable energy procurement target. The renewable energy variance can then be based on the technology's past performance.[4]

- ρ_{jk} = Correlation coefficient between variables j and k for $j \neq k$ and $j, k = Q, P, Y$. This can be based on the historic correlation data.
- $\sigma_{jk} = \rho_{jk}\, \sigma_j \sigma_k$ = Covariance between variables j and k, constructed using the forecast standard deviations and the historic correlation data.

Using these variables, the LSE's procurement cost is:

$$C = (Q - X - Y)\, P + FX + RY = PQ - PX - PY + FX + RY \qquad (1)$$

where $(Q - X - Y)$ = LSE's residual net short position transacted at the spot market price. The LSE's expected cost is:

$$\begin{aligned} \mu &= \mathrm{E}(C) \\ &= \mathrm{E}(PQ) - \mathrm{E}(PX) - \mathrm{E}(PY) + \mathrm{E}(FX) + \mathrm{E}(RY) \\ &= (\mu_P\, \mu_Q + \sigma_{PQ}) - \mu_P\, X - (\mu_P\, \mu_Y + \sigma_{PY}) + FX + R\mu_Y \\ &= [\mu_P\, \mu_Q - (\mu_P - F)\, X - (\mu_P - R)\, \mu_Y] + \sigma_{PQ} - \sigma_{PY} \qquad (2) \end{aligned}$$

because $\mathrm{E}(AB) = \mathrm{E}(A)\, \mathrm{E}(B) + \mathrm{Cov}(A, B)$ for random variables A and B.[5]

Equation (2) has a nice interpretation. When the LSE's sale obligation Q, the spot market price P, and renewable output Y are statistically independent, the [ ] term on the right-hand-side is (a) $\mu_P\mu_Q$, the LSE's cost of expected sales at the expected price; net of (b) $(\mu_P - F)\, X$, the expected profit from forward purchase, and (c) $(\mu_P - R)\, \mu_Y$, the

[4] For instance, if the K MW of existing capacity leads to an average output of M MWH with a daily variance V^2, a forecast of K_F MW of capacity would produce $M\,(K / K_F)$ MWH of energy with a daily variance of $V^2(K / K_F)^2$.

[5] Mood AM, FA Graybill and DC Boes (1974). Introduction to the Theory of Statistics, McGraw Hill, p.180.

expected profit of renewable energy output. But if *Q, P* and *Y* are not independent, the LSE's expected cost μ depends on (a) σ_{PQ}, the covariance between *P* and *Q*; and (b) σ_{PY}, the covariance between *P* and *Y*.

Empirical evidence indicates $\sigma_{PQ} = \rho_{PQ}\sigma_P\sigma_Q > 0$ as *P* and *Q* are positively correlated, implying that rising sales always adds cost. However, adding renewable energy does not always reduce LSE's expected cost. For instance, if renewable energy output (e.g., wind) is high during low-price hours so that $\sigma_{PY} = \rho_{PY}\sigma_P\sigma_Y < 0$, contracting for more renewable energy (even at $R = \mu_P$) may raise the LSE's expected cost. To be sure, if renewable energy (e.g., solar) and market prices are positively correlated so that $\sigma_{PY} = \rho_{PY}\sigma_P\sigma_Y > 0$, contracting for more renewable energy (even at $R > \mu_P$) may reduce the LSE's expected cost.

Based on equations (1) and (2), we derive the LSE's cost variance σ^2. Our cost variance focus departs from the (cost expectation / return volatility) representation in the two staff papers for two reasons. First, the direct and transparent relationship between expected cost and cost variance enables an explicit formulation of the minimum cost variance problem (subject to a cost expectation constraint), whose solution is a meaningfully derived EF.[6] Second, cost variance matches the concerns of electricity consumers and regulators. We can use the value-at-risk (VaR) concept to a (μ, σ^2) pair

[6] Woo, C.K., I. Horowitz, B. Horii and R. Karimov (2004) "The Efficient Frontier for Spot and Forward Purchases: An Application to Electricity," Journal of the Operational Research Society, 55, 1130-1136;

on the EF, thereby establishing the procurement cost ceiling that consumers would likely see under normal circumstances (with say, 95% probability).[7]

Since the forward purchase cost FX is not random, the LSE's cost variance is:

$$\sigma^2 = \mathrm{Var}(PQ) + \mathrm{Var}(PX) + \mathrm{Var}(PY) + \mathrm{Var}(RY) - 2\,\mathrm{Cov}(PQ, PX) - 2\,\mathrm{Cov}(PQ, PY) + 2\,\mathrm{Cov}(PQ, RY) + 2\,\mathrm{Cov}(PX, PY) - 2\,\mathrm{Cov}(PX, RY) - 2\,\mathrm{Cov}(PY, RY) \qquad (3)$$

Equation (3) states that the variance of the LSE's procurement cost is the sum of the following terms:[8]

- $\mathrm{Var}(PQ)$ = Variance of the LSE's sale obligation Q at the spot market price P, whose computation entails $\mathrm{Cov}(P, Q)$ and other multiplicative terms.[9]
- $\mathrm{Var}(PX)$ = Variance of the LSE's X MWH of forward purchase at P.
- $\mathrm{Var}(PY)$ = Variance of the renewable energy output Y at P.
- $\mathrm{Var}(RY)$ = Variance of the LSE's payment for Y MWH of renewable energy at fixed price R.
- $\mathrm{Cov}(PQ, PX)$ = Covariance between PQ and PX.
- $\mathrm{Cov}(PQ, PY)$ = Covariance between PQ and PY.
- $\mathrm{Cov}(PQ, RY)$ = Covariance between PQ and RY.
- $\mathrm{Cov}(PX, PY)$ = Covariance between PX and PY.
- $\mathrm{Cov}(PX, RY)$ = Covariance between PX and RY.

[7] For an application of the VaR concept, see Woo, C.K., R. Karimov and I. Horowitz (2004) "Managing Electricity Procurement Cost and Risk by a Local Distribution Company," Energy Policy, 32:5, 635-645.

[8] An example of how to compute the variance and covariance terms in equation (3) is in Woo, C.K., R. Karimov and I. Horowitz (2004) "Managing Electricity Procurement Cost and Risk by a Local Distribution Company," Energy Policy, 32:5, 635-645.

[9] The variance of the product of two random variables is given by Equation (13) in Mood AM, FA Graybill and DC Boes (1974). Introduction to the Theory of Statistics, McGraw Hill, p.180.

* $\mathrm{Cov}(PY, RY)$ = Covariance between PY and RY.

The covariance terms above indicate that even for a simple 1-period model of LSE procurement, the computation of the LSE's cost variance requires not only the correlation between a price variable (e.g., P) and a quantity variable (e.g., Q or Y), but also the correlation between two product terms (e.g., PQ and PY). Happily, these correlation estimates can be based on the LSE's load data, the market price data and the metered output of renewable energy.

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